8
HISTORICAL EVOLUTION

A gearbox and clutch, or alternative start-up devices, are essential for obtaining a driving torque suitable to traction from a reciprocating internal combustion engine.

In fact, this category of engines is characterized by a useful torque almost constant with rotational speed and sometimes increasing with it; in an ideal case, on the contrary, the driving torque should decrease with vehicle speed.

We can say that having decided to install an engine of a given power, considering the desired dynamic performance, this power should be made available at any vehicle speed; the traction force should therefore be inversely proportional to vehicle speed.

This choice would also guarantee vehicle speed stability, because a driving force decreasing with speed would balance a resistance force increasing with speed.

In addition, the internal combustion engine is unable to supply a positive torque if its rotational speed is less than a minimum value, whose amount is determined, as a first approximation, by the torque period of the cycle and the inertia of the crank mechanism. The vehicle, however, must be able to start-up when stopped and should be able to exploit, in this condition, the maximum driving torque.

For these reasons it is necessary to have a mechanical system available able to adapt the transmission ratio between engine and wheels to the needs of the vehicle and the deficiencies of the engine. This transmission ratio should be extremely high, ideally infinite, at vehicle start-up.

Finally, the transmission has the purpose of transmitting the motion of the engine crankshaft to the wheel hubs; as we know, wheels and engine have a

G. Genta and L. Morello, *The Automotive Chassis, Volume 1: Components Design*, Mechanical Engineering Series,

relative position not defined with precision, because of the motion of the suspension and the steering of the wheels.

In the first cars, the gearbox was confused with a device for speed adjustment; from this misinterpretation was also born the name of this device, almost equivalent in many European languages (for instance, *changement de vitesse*, in French). This term was used instead of torque converter or torque adaptor, more suitable to the real role of this mechanism.

These considerations, taken today for granted, were not so evident to the designers of the first cars, which were equipped with a steam engine. Among many disadvantages for vehicular application, such engines have the advantage of being able to supply a notable torque when the crank is stopped, quite suitable for vehicle application.

This situation is exemplified by the Cugnot cart of 1769, unanimously recognized as the first self-propelled vehicle.

Figure 8.1 shows a drawing of the transmission mechanism between pistons and driving wheel. The sole driving wheel is positioned in front of the vehicle and can be steered along with the steam cylinders and boiler (not represented); no suspension is applied.

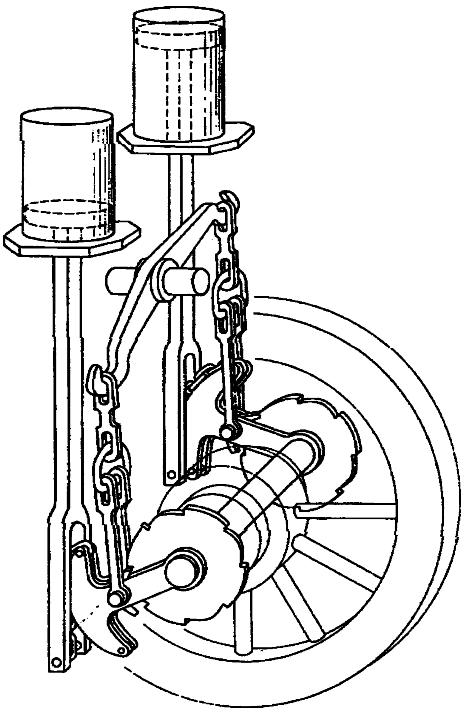

FIGURE 8.1. Drawing of the transmission mechanism from the piston to the wheel in the steam engine cart designed by Cugnot in 1769.

Engine rods are directly connected to the wheel through ratchet gears that convert reciprocating motion of the piston into wheel rotation.

This direct link, eventually made, more simply, with a crank mechanism, was also applied to other steam coaches and used widely on steam train locomotives.

The first operational internal combustion engine vehicle was probably introduced by De Rivaz in 1807. It adopted a similar transmission and exploited the ratchet gear mechanism to keep the vehicle moving under the action of inertia, during the non-useful strokes of the piston.

8.1 MANUAL GEARBOX

Patent documents of 1784 give evidence that Watt foresaw the use of a constant mesh gear box, with dog clutches, to improve the traction performance of a steam engine; it is rather difficult to demonstrate how this idea might have influenced the design of ensuing cars, which did not follow this scheme indiscriminately.

The first commercialized internal combustion engine cars are, without doubt, those born of the efforts of Benz and Daimler in 1885 and 1886; the transmission problem was solved using a scheme completely different from that proposed by Watt.

The complete Daimler car transmission is shown in Fig. 8.2. There are two different transmission ratios made with leather belt transmissions with pulleys of different diameter; the belts are always wound on their pulleys, but the motion is transmitted by only one of the couples, when one of the two tensioners 55 (for the first speed) and 56 (for the second speed) sets its belt at work.

Belt slip capacity is exploited, when the tensioner is not completely engaged, to start-up the vehicle when stopped.

Wheel suspensions are missing and the driveline is consequently simplified.

Many improvements of this scheme were applied to the following Benz car. The two speed transmission was inspired by contemporary workshops, where a single steam or water engine moved a number of working machines. This kind of transmission was probably invented by Anderson in 1849.

The two driven pulleys (in the center of the lower drawing in Fig. 8.3) are coupled with as many idling pulleys (at the outside faces of the driven pulleys); these have a slightly smaller diameter than the driven pulleys and the active cylindrical surface of the driven pulleys is rounded to join the active surface of those idling.

The two driving pulleys (in the back of the car, aligned with the engine crankshaft) have an adequate width to bear the belt on both driven and idling pulleys. Two tensioners can shift the leather belts from matching driven pulleys to matching idling pulleys.

The belts are crossed in order to increase the winding angle on the pulleys; belt tension is adjusted periodically, by changing the distance of the center lines.

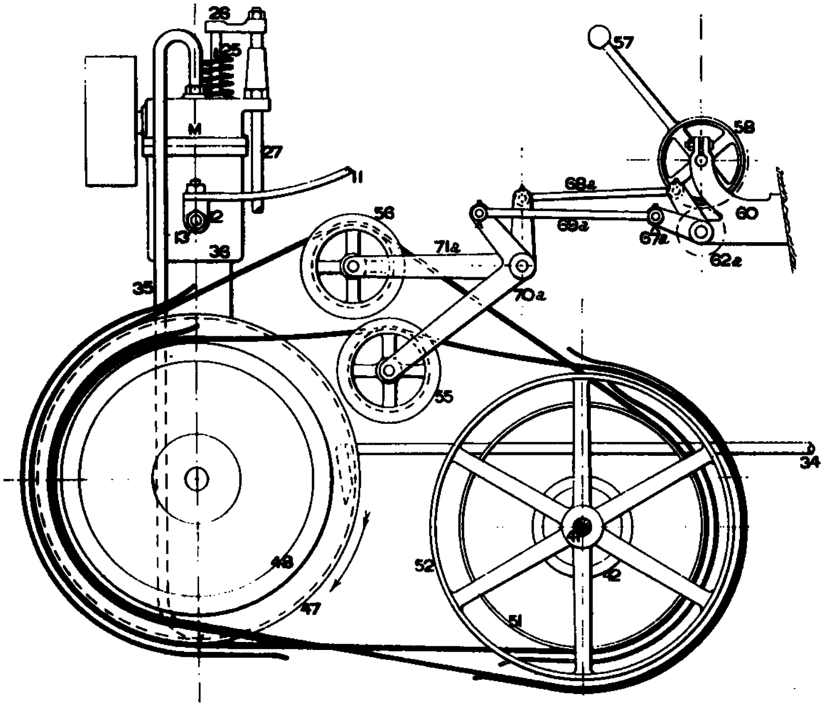

FIGURE 8.2. Complete transmission of the Daimler car of 1885. Two transmission ratios are available, made with a leather belt transmission. The slipping capacity of the belts is exploited to start-up the car.

The rounding on the surface of the driven pulleys makes belt shifting easier; the lower diameter of the idling pulleys decreases the working tension of the belts when they are not working, retarding the need for further tension adjustments.

The start-up function is again performed by exploiting the belt slip capacity; the almost vertical motion of the driving wheels, already using a suspension, is compensated for by two chain transmissions that connect the driven pulleys with the rear wheel hubs.

It should be noticed that the literature on these and other cars of this time did not suggest a sequential use of gears to accelerate the car, but starting-up was allowed with both gears, the choice bound rather to the desired cruise speed, than to the necessary traction force.

The idea introduced by Watt would be applied on next generation design. This is usually noted by saying that the first cars demonstrated how the technical skills of their inventors were polarized on engines, sometimes neglecting the subject of other achievements that had been already obtained in the contemporary state of the art. This fact could be also explained by the difficulty of exchanging ideas through the technical communities of diverse countries.

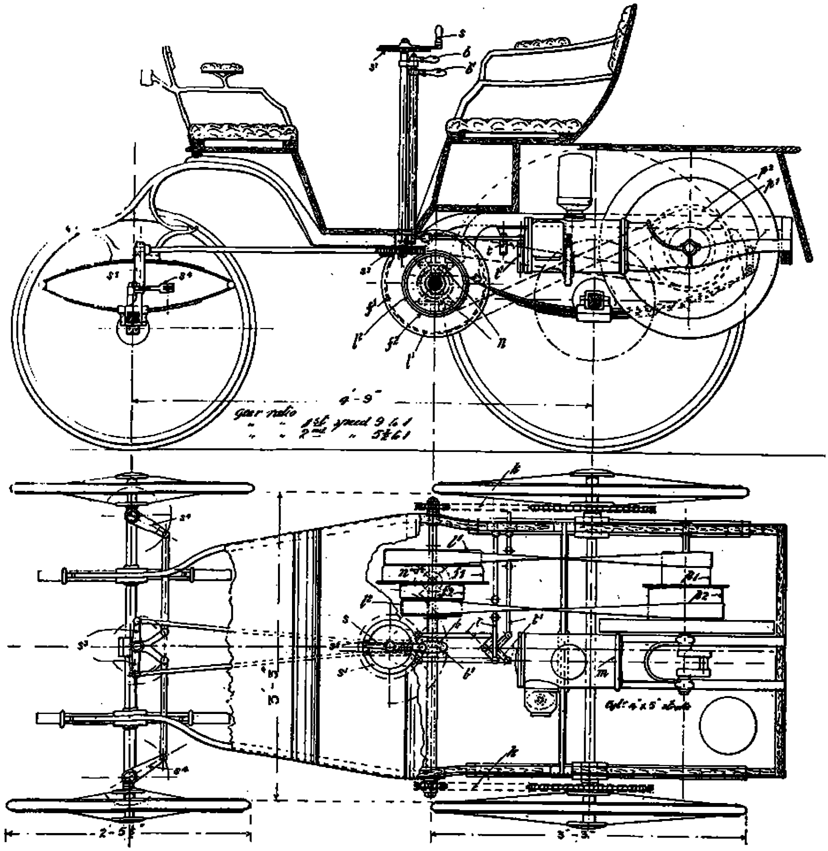

FIGURE 8.3. Two speed transmission of the Benz car in 1886, leather belt type. Two tensioners can shift belts from a position engaged with a driving pulley to that engaged with an idling pulley.

A typical example, similar to contemporary situations, is represented in Fig. 8.4, where a drawing of the FIAT 8/16 HP of 1902 is shown.

The gearbox features three speeds and a reverse; in the oldest cars the reverse speed was missing.

The engine rotates the lower shaft, at the left, a view that represents a side view of the gearbox. This gearbox has a single reduction stage, where all driving tooth wheels are aligned with the input shaft and all driven wheels with the output shaft; on the engine side, we first see the reverse gear, followed by first, second and third gears.

An idle tooth wheel can be noticed, used to reverse the rotation speed of the output shaft on the cross section at the left of the side view.

Driving wheels always mesh with driven wheels and must, therefore, be idle in relation to the output shaft; we will see later how they are engaged. The output shaft rotates a bevel gear, which moves two shafts through a differential.

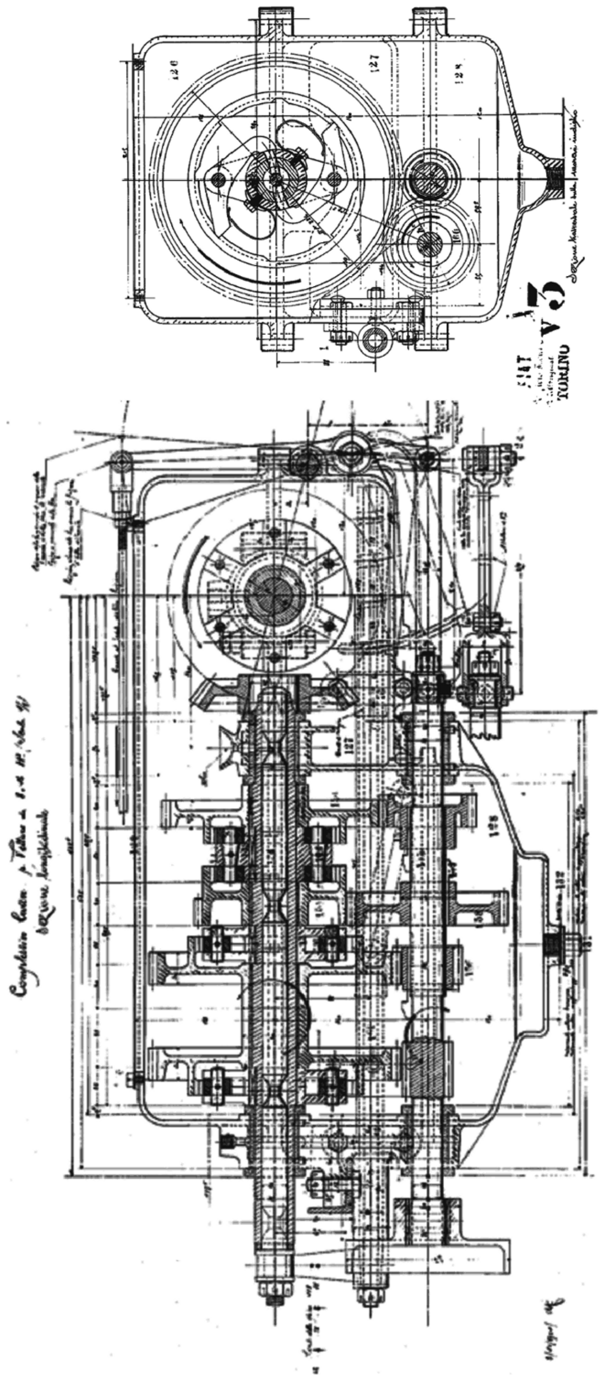

FIGURE 8.4. Single stage, three gear gearbox of the FIAT 8/16 HP of 1902. The internal shifting mechanism is made by a cylindrical rod, mounted inside the driven shaft.

These are coupled through drive chains to the rear driving wheels, according to the scheme already commented on in the previous figure.

A tapered friction clutch, not represented in this figure, allows vehicle start-up and separates the gearbox from the driveline during gear shifts (see for reference Fig. 8.12).

We can notice three new mechanisms not yet introduced: Reverse gear, differential and friction clutch. Their origin is surely older than this car. The reverse gear was introduced by Selden in 1879, the differential by Pecquer in 1827 and the tapered friction clutch by Marcus in 1885.

During these years these three mechanisms were integrated in a transmission suitable for automotive application.

Let us now look at the shifting mechanism. It is rather sophisticated, made by a shiftable cylindrical rod mounted inside a cavity in the driven shaft. This rod shows some annular narrowing, which in certain positions allows two ratchets to engage with the driven wheels; the detail of the reverse gears ratchets can be seen in the cross section on the left.

When one of the grooves faces a pair of ratchets, two leaf springs provide for their engagement with the ratchet gear; when the rod is shifted, ratchets retract, leaving the wheel again idle. The position of the grooves is congruent with a sequential shift stick, where the positions of reverse, first, second and third follow each other.

This kind of gearbox architecture (constant mesh gears) is applied to many cars of that era, but will be soon abandoned because of its complexity and consequent fragility. The next scheme is that of *sliding gear trains* (*train balladeurs*, in french). This invention is older than the automotive world and born outside of it; its emergence was the work of Griffith in 1821.

It is not the first time that a better performing architecture (constant mesh) is abandoned in favour of a less evolved alternative (sliding trains), because a particular component (dog clutch, synchronizer) has not been developed yet. Sliding trains will soon be abandoned again, in favor of constant mesh, when the technological improvements make it possible.

Sliding trains can be exemplified by the FIAT 60 HP car of 1904, whose gearbox is shown in Fig. 8.5.

The gearbox is still of the single stage type and presents four speeds and a reverse speed; tooth wheels, grouped in two trains, from the first to the fourth, can slide on the upper driving shaft. The engine (not shown) is on the left, while on the right we can see bevel gears moving the pinion of the chain transmission through the differential.

The two trains integrate, respectively, first and second speed wheels, and third with fourth; these trains are mounted on a square section shaft that allows them to turn with the shaft, being free to shift along it.

Train sliding is accomplished by suitable sleeves that bring one wheel at a time to engage with its counterpart; the gears mesh only when their correspondent gear is selected.

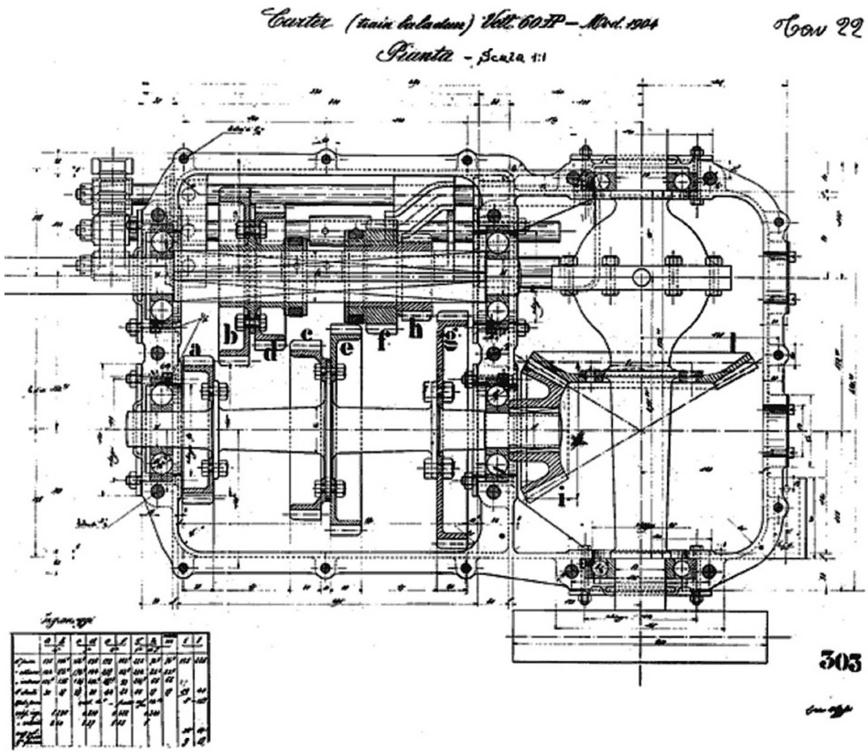

FIGURE 8.5. Sliding train gearbox with four speeds of the FIAT 60 HP of 1904. The two gear trains are made by the driving wheels of the first and second speed and by those of third and fourth speed.

Reverse speed is accomplished by a train of idler gears only, not represented in this figure, meshing with the first speed gears, when their train is in the idle position.

The sleeves are moved by forks fixed to sliding rods, partially visible under the gearbox shafts; there are two rods for moving the first and second train and the third and fourth train, while an additional rod is dedicated to reverse speed.

This kind of lay-out has created the need for selection and shift control sticks, where gear shifting is no longer sequential, but is characterized by two separated motions: one across the car, to select the train to be engaged, the second along the car, to engage the specific gear. This layout will consolidate in practice, surviving unchanged in our contemporary cars.

Sliding train gearboxes required a particular skill of the driver, who had to synchronize the wheels by means of the engine during idling, before engaging the next gear (double clutching or *débrayage double*, in French); an imperfect maneuver was indicated by scratching of the gears in contact at an inappropriate speed.

Some manufacturers improved this architecture, actually returning to Watt's idea of constant mesh gears; an industrial vehicle gearbox of the end of the 1910s is represented, to show this new lay-out, in Fig. 8.6.

In this gearbox three speeds are available and a reverse speed; the gearbox is connected to the engine on the right of the figure, while the output flange is on the left. The flywheel on the output shaft is not part of the engine, but is the drum of the transmission brake.

Input and output shafts are now coaxial; this lay-out is appropriate to the application of a universal joint transmission, beginning to be applied in these years.

Tooth wheels are in constant mesh and have at their flanks a dog clutch; sliding trains are now reduced to the pairs of dog clutches.

The scratch problem is not solved, but possible damages are localized on an auxiliary component, the clutch, that can be sacrificed, with smaller impact on the operation of the gearbox. Dog clutch teeth can also be rounded, making shifting easier, without penalty for wheel dimension.

We can observe that input and output shafts are coaxial, the upper shaft made by two parts, free to have different rotation angles. The left sliding train can alternatively engage the two parts directly or move a third shaft (*countershaft*), below in the same figure.

Only with this dog clutch engaged is it possible to obtain first and the second speeds, with the second train in the figure; with the last train it is possible to engage the reverse speed, connecting the countershaft to the output shaft and then to a pair of idlers (in practice a second countershaft), partially visible on the right of the figure.

Sliding train motions are operated by front cams, that allow in this case sequential control.

A similar architecture, but for control, is still present in front engine, rear wheel driven vehicles.

We should not fall into the mistake of thinking that at this time these technical solutions were consolidated; as often occurs at the dawn of a new technology, deviations from what, for us, is the primary evolutionary path were many. We can see that, after the engine, the gearbox was the preferred subject of innovation of the first automotive engineers.

A comprehensive classification of all attempted solutions is well outside the scope of this chapter, even limiting the discussion to manual transmissions; we will only consider what are in our view some of the more original solutions.

Between 1924 and 1938 Frazer Nash in England built different cars, all with sport performance but affordable price in their category. Essential to these cars was the driveline, as can be seen in Fig. 8.7.

The gearbox is made from chain transmissions, three for forward speeds, one for reverse speed. Driving chain wheels (at right in the drawing) are moved by a bevel gear box, connected to the engine; this bevel gear box includes no differential gear.

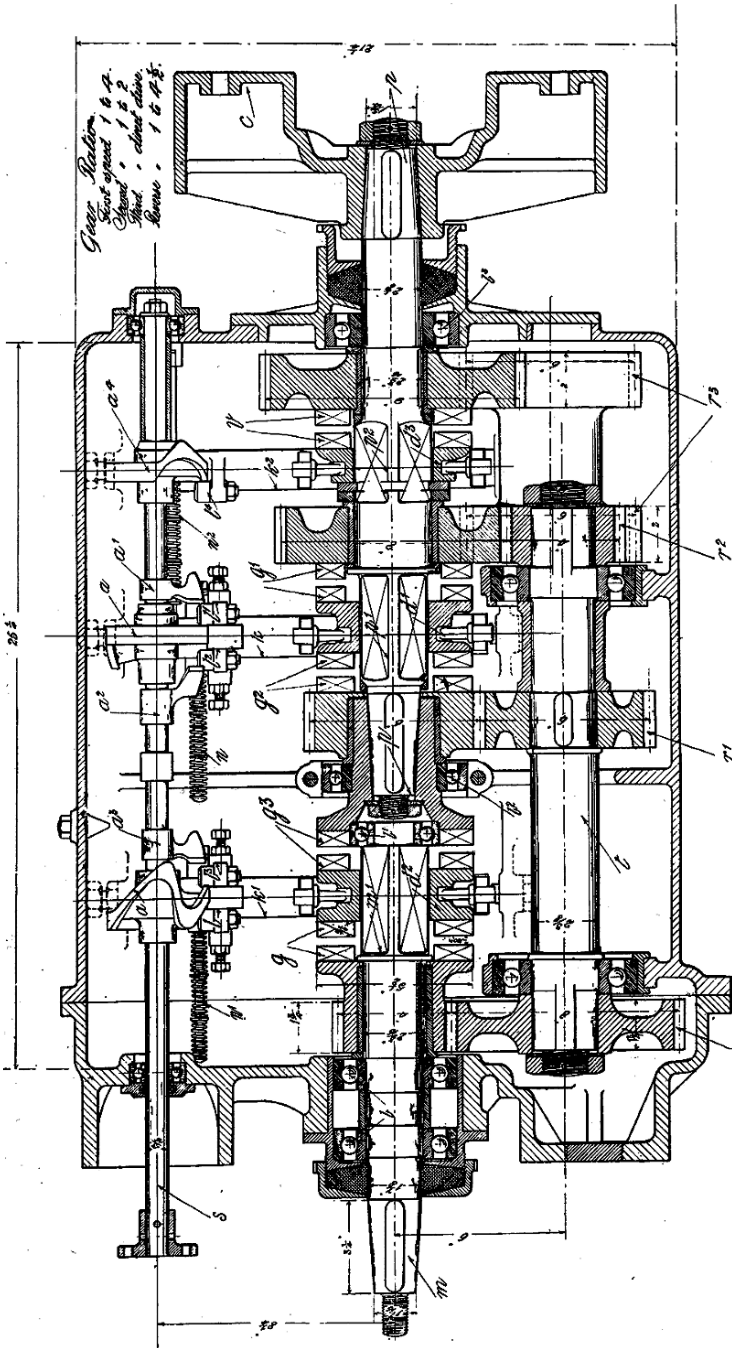

FIGURE 8.6. Dog clutch truck gearbox of a vehicle made in the 1910s. Sliding trains are now reduced to small front tooth gears working as clutches.

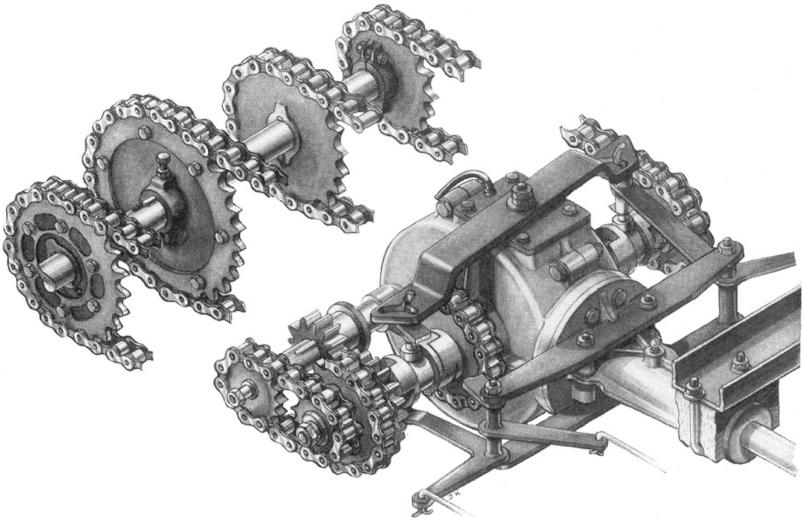

FIGURE 8.7. Frazer Nash gearbox of 1924, made by chain transmissions only; three speeds and a reverse are available. The driven shaft can be adjusted to obtain good alignments and to compensate for chain wear.

On the right half shaft of this intermediate shaft are fixed the sprockets for first speed and reverse; on the left half shaft are sprockets for second and third speed.

Notice the idler reverse system with chain and gears. Driven wheels are directly mounted on the rear one piece shaft; driven wheels can be moved along their shaft for chain alignment.

The lack of the differential made the car difficult to drive, but very manageable for an expert driver on unpaved roads, common in those times.

A chain transmission was also used for compensating for suspension motion.

Engagements were made by simple but sensitive dog clutches. Admirers of these cars extolled the easy road holding, the excellent gearbox maneuverability and the ease with which broken parts could be replaced in the transmission.

The entire mechanism was lubricated by grease in the open air. We can also notice the rocker arm, on the bevel gear box, with particular slots, that match the engagement forks; this mechanism avoided the simultaneous engagement of two speeds, significant considering the effect of centrifugal forces and vibrations.

A car with different technical details, also original and uncommon, is the Sizair Naudin of 1907, also known for featuring one of the first independent suspensions.

Here the design goal should have been to contain gearbox cost, or at least the number of tooth wheels, at that time quite expensive.

The gearbox architecture in Fig. 8.8 can be assimilated to a sliding train gearbox. Driven wheels are reduced to one, with front teeth R. The only sliding train, made by wheels P1, P2 and P3, is installed on a bearing swinging around

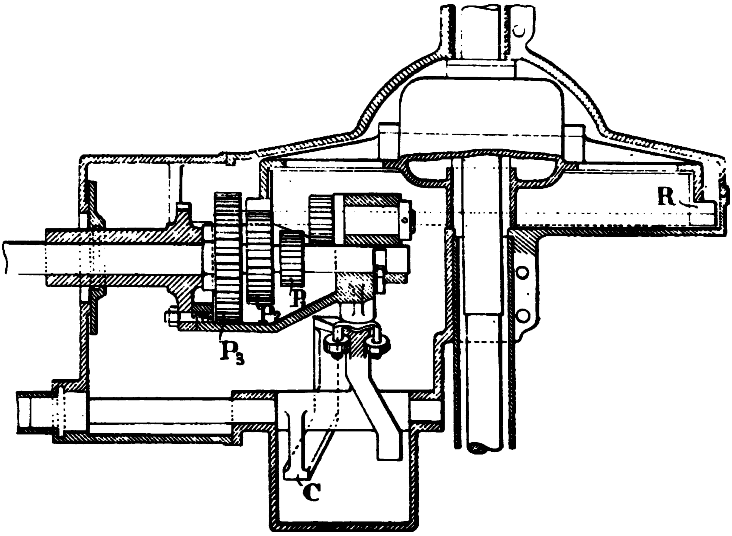

FIGURE 8.8. Sizair Naudin gearbox of 1907. This design can be assimilated to a sliding train gearbox, with bevel gears. The single sliding train made by wheels P1, P2 and P3 is mounted on a swinging bearing to mesh the driving shaft at different distances with the big output front teeth wheel.

the lower shaft in the drawing; the swinging motion of the bearing is necessary to mesh the driving wheel in use with the front teeth wheel, at different distances, depending on the driving wheel diameter.

The swinging motion of the driving shaft is compensated for by a universal joint transmission between engine and gearbox. The cam C at the bottom of the drawing combines shift and swing motions and bears gearing forces.

The spur wheel should instead be bevel gears, for correct matching; the teeth are, nevertheless, approximated with cylindrical teeth, accepting contact errors.

The reverse idler is also present on a dedicated shifting train.

A last example of amazing engineering ingenuity is given by the Turicum of 1904 (probably the only automotive trademark in Switzerland) shown in Fig. 8.9, with a picture of the complete chassis: Here we see one of the first continuously variable transmissions in the history of the automobile.

Nor does this care have a differential; the motion of the rear axle is transmitted with two friction wheels C and D, the first made of solid iron, the second with a rubber tread on its rim. The wheel D is fixed on the shaft E with a spline and groove, that allows the wheel to be shifted along the shaft; the shaft E rests on a swinging bearing G and maintains wheels D and C under pressure with the spring J.

By pulling the lever q it is possible to change the contact point between the two pulleys, between the center of the wheel C (infinite transmission ratio: transmission idling) and its rim (transmission ratio about 1:1). In the idle position,

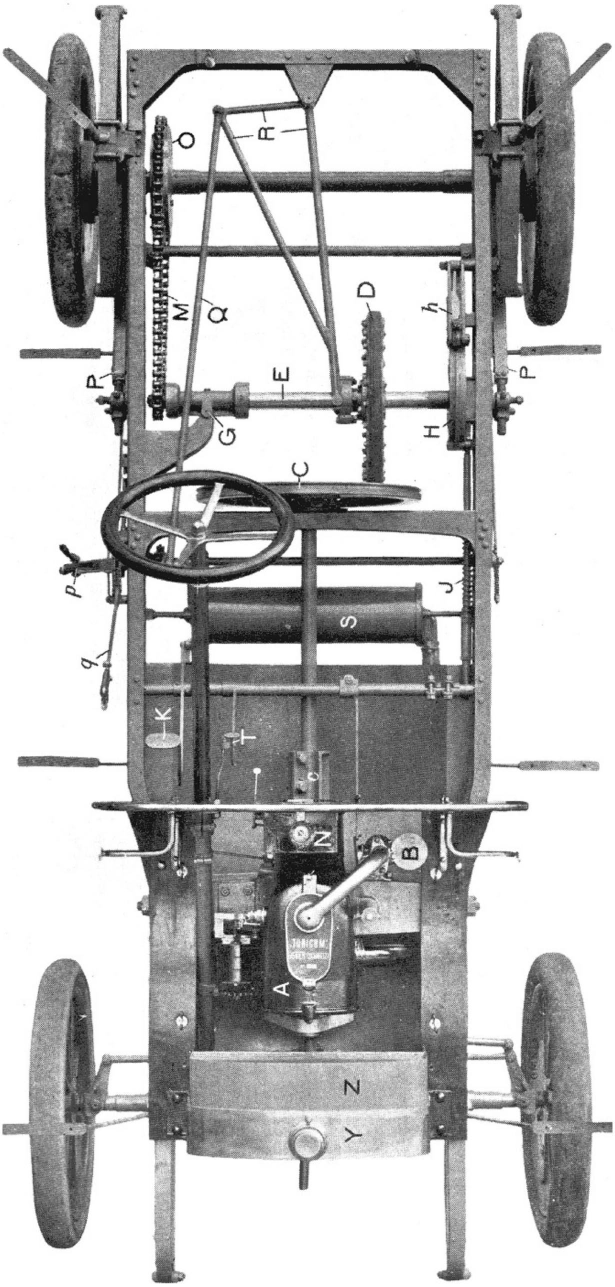

FIGURE 8.9. Turicum chassis of 1904; here we see a continuously variable transmission based upon two friction discs C and D, where the first is made of solid iron and the second has a rubber thread to improve contact friction.

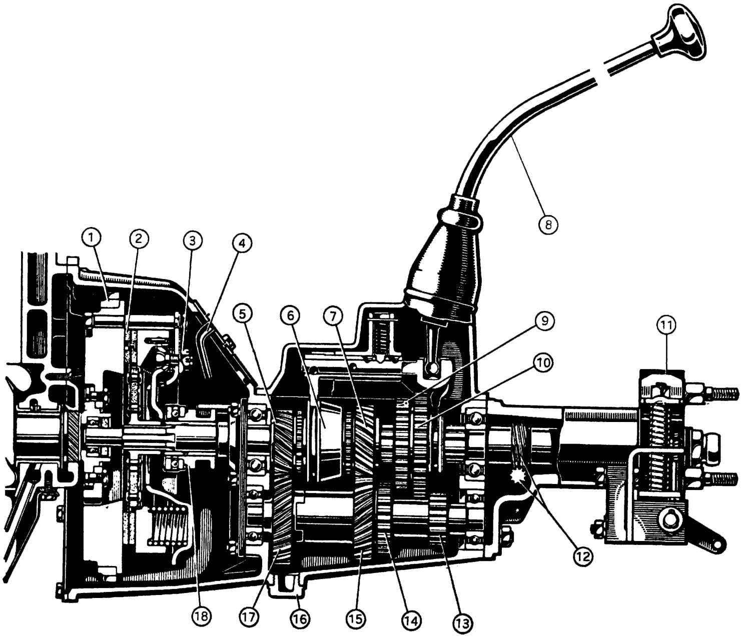

FIGURE 8.10. Four speed gearbox of the FIAT Balilla of 1934. The drawing shows a longitudinal cross section; the rear of the gearbox has a sliding train for first, second and reverse speeds; the front features synchro-mesh gears for the third and fourth speeds.

the friction is eliminated by unloading the spring J; the possible slip between the two wheels is used to start the vehicle up.

These proposals were not imitated by other manufacturers and were probably abandoned by their own inventors. The evolution of manual gearboxes concentrated on perfecting a countershaft or double stage architecture, that became universal on all cars with front engine and rear drive.

An example of this evolution is offered by the gearbox of the FIAT Balilla of 1934 (four speed version, the first gearbox of this car in 1933 was a three speed design) shown in Fig. 8.10.

This gearbox shows two different sections: The rear, for first, second and reverse speeds, features a sliding train with cylindrical straight teeth. The front features helical gears (always meshing) and synchronizers.

This compromise is justified by the high cost of synchronizers, considered high technology components at the time. Synchronizers are limited to the more frequently used speeds, which can also benefit of helical gears, with gearing noise reduction.

On this subject, we notice that engineering manuals of this time suggested, as a good engineering practice, to design the top ratio (in this case the final differential ratio) with values slightly higher then that ideally necessary; this rule was addressed to limiting the number of gearshifts necessary to maintain

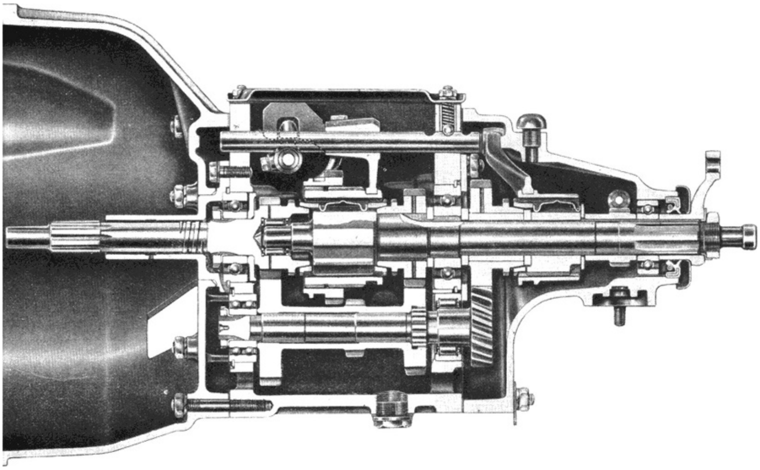

FIGURE 8.11. Four speed gearbox of FIAT 1400 of 1950, with full synchronization, except for the first gear. The reverse speed is made by a sliding idler, not shown in this figure.

the car at cruise speed, and demonstrated the difficulty for drivers to change speed with sliding train gearboxes.

We can therefore assume that synchronizers brought benefits not only for shifting quality, but also for noise and fuel economy.

The gearbox of the FIAT 1400 of 1950, shown in Fig. 8.11, adopts, as do many cars of this time, synchronizers on all speeds but the first, again for reasons of economy; the first is included in a sliding train mounted on the sleeve of the third and fourth speeds. The reverse speed is made with an idler, not shown in the picture, meshing with the first wheels when they are in neutral position.

During the ensuing period, synchronizers were improved and made less expensive thanks to higher volumes; since the 1970s also economy cars have received synchronizers on all forward speeds.

8.2 FRICTION CLUTCHES

An important transmission component, the friction clutch, or, simply, *clutch* posed many problems to designers about operating force and endurance.

In the earliest cars, belt transmissions integrated the clutch function into the gearbox. As we have already seen, bevel clutches were known even at the beginning of the automobile era.

We see on Fig. 8.12 an example of bevel clutch of the first years of the past century.

The friction surface is covered by a leather lining, riveted on a bevel pulley of cast iron; although Frood had already invented the famous synthetic material called Ferodo in 1897, it became widely applied only in the 1920s.

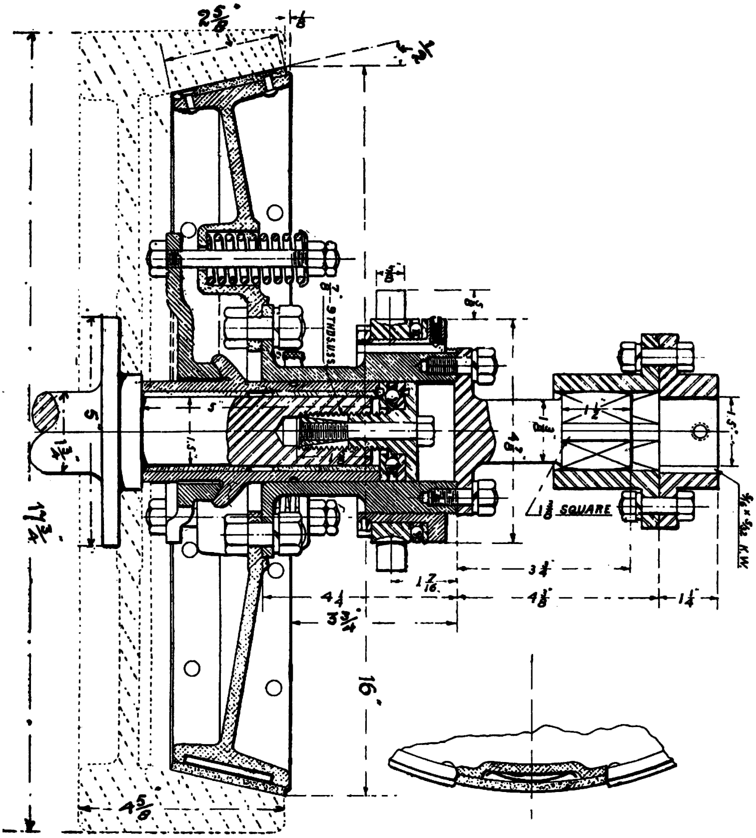

FIGURE 8.12. Bevel clutch with leather linings. Clutch conicity (1:2; lower values could reduce pedal reaction) is limited by the available friction coefficient to avoid irreversible sticking of working surfaces after engagement.

Leather has a friction coefficient similar to modern friction materials, but offers limited performance in terms of heat wasting capacity and endurance; these facts implied a large sizing of active surfaces. On the other hand, leather was, in those times, cheap and easily repaired or replaced.

The active surface of this application is single and shaped like a cone; this shape was chosen to limit the disengagement force on the pedal, which depended upon the cone diameter and engine torque. Due the difficulty of integrating the leather lining into its support disc, the active surface was usually single rather than double, as it would be in modern clutches.

If we refer again to the previous figure, we can notice that the engine flywheel features a short shaft bearing the reaction structure of the load springs working on friction surfaces.

Many coil springs (only one is shown in the cross section) push the tapered friction disc into the flywheel. The leather lining is riveted on this disc; very thin

leaf springs are set between the lining and the disc to make the engagement more progressive.

With this kind of architecture, much different from contemporary methods, the gearbox input shaft must be able to slide on a square counterpart.

Friction conicity (1:2 on this drawing) is limited by the friction coefficient between leather and iron, in order to prevent irreversible sticking of the clutch after engagement.

The large engine displacement of many cars and the limited dimension of the flywheel made many clutches too heavy to be operated; for this reason other mechanisms were also developed.

The idea was to exploit the mechanical property of wound linings to reduce working forces. Here the friction force is itself used to increase contact pressure, as through the leading shoes of drum brakes. This principle was applied through band clutches.

An application of this principle is shown in Fig. 8.13; a coil spring with rectangular section is installed in a cavity in the flywheel; the coils are quite close to each other. One end of the spring is fixed directly to the flywheel, through the eye in the lower part of the figure; the other end is instead connected by a rocker arm D.

If an ogival body is moved closer to the rocker arm, it is possible to twist the spring and reduce its internal diameter.

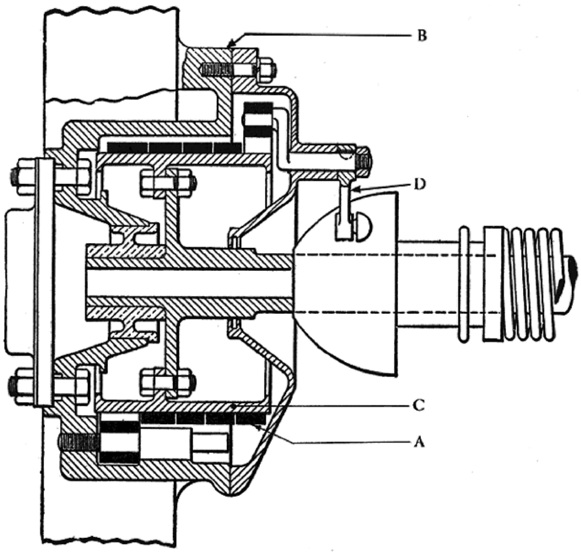

FIGURE 8.13. Clutch with spiral friction spring. The clutch pedal moves the ogive that closes the spring onto the input shaft, creating a friction force; the same force increases the band tension. The resulting friction torque is a function of the initial tension through an exponential function of the winding angle of the spring.

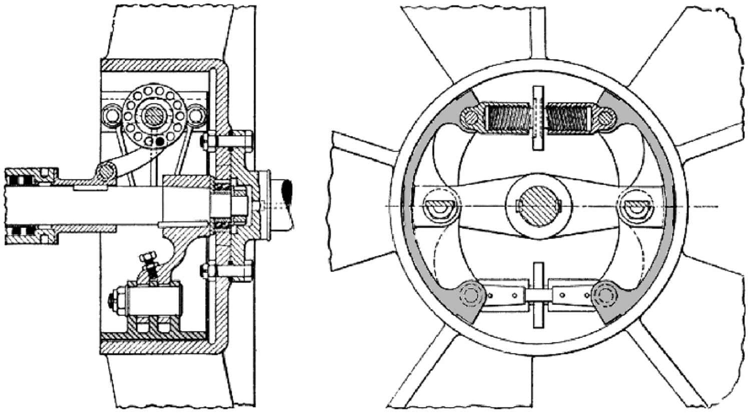

FIGURE 8.14. Radial shoes clutch. The shoe displacement is caused by a screw mechanism, operated by the clutch pedal through a crank.

The gearbox input shaft C is surrounded by the spring with a slight play; when the ogive is advanced through the clutch pedal the spring closes on the shaft with a resulting friction torque.

The friction tension along the spring coil increases the tangential tension toward the eye, without increasing its reaction on the rocker arm; the resulting friction torque is an exponential function of the winding angle, which can be increased indefinitely.

With a modest friction coefficient between metals it is possible to transmit the desired torque with a reasonable force on the pedal; the downside is the difficulty of the engagement maneuver, only partly eased by spring elasticity.

A very different configuration of the same principle is given in Fig. 8.14; the torque is transmitted by two shoes that expand in a drum, as in a drum brake.

The shoe motion is created by a screw that is moved through a crank and rod mechanism; the disc shape of the crank is chosen to allow a simple play adjustment, to compensate for lining wear.

Faced with a difficult problem, inventors investigated many different solutions before consolidating and improving the best one; to solve these problems electric and hydrostatic transmissions were also investigated and applied.

The final solution was consolidated in the 1930s with the single disc clutch with synthetic friction linings; one example from this period is shown in Fig. 8.15.

The friction surface is now flat and double; with the same force it is possible to transmit a double torque. The friction disc is mounted within two surfaces (the flywheel and the pressure disc) that are compressed by a number of coil springs; a set of levers on the pressure disc are used to release the clutch with the axial motion of a thrust bearing.

This kind of clutch received its last improvement by the application of cup springs; these were introduced at the end of the 1970s and allowed many advantages, such as a further reduction of pedal force and a general simplification of the mechanism.

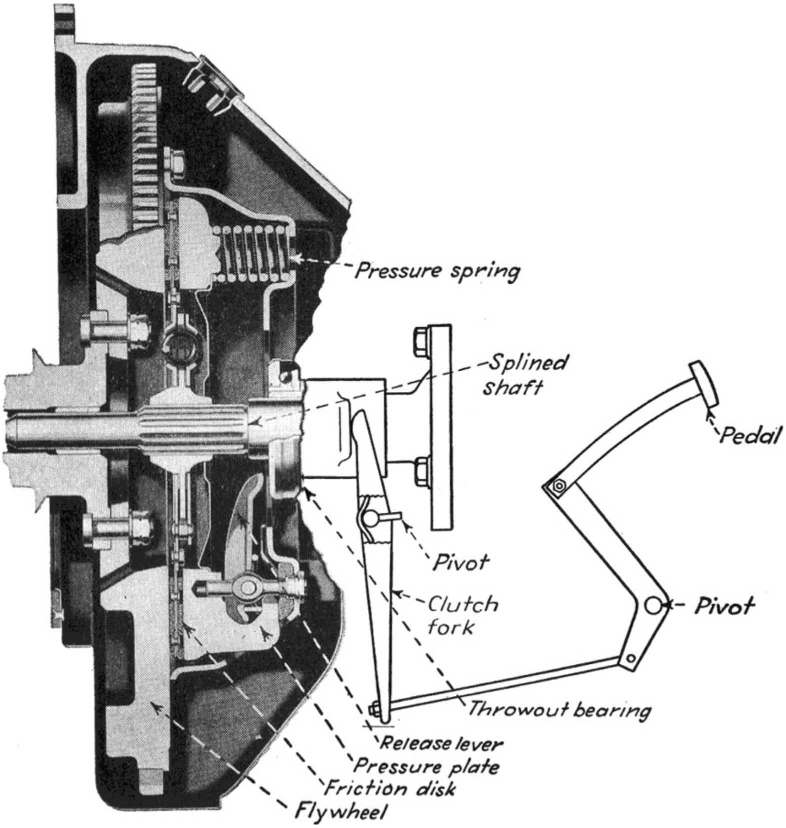

FIGURE 8.15. Dry single disc clutch with coil pressure springs. A set of release levers articulated on the pressure plate is used to disengage the clutch, through the displacement of the throwout bearing.

8.3 AUTOMATIC GEARBOXES

Automatic gearboxes have had their own history, one that received a crucial contribution from the American automotive industry.

We do not suggest that Europe failed to contribute to this development; we will see, in fact, that many fundamental inventions were developed on this continent. Nevertheless the European market, smaller and more fragmented, did not justify the mass production of this gearbox until recently.

The problems to be solved in developing an automatic gearbox included a different mechanism for engaging gears and starting the vehicle, easier to operate with less sophisticated automatic controls. These could be mechanical (exploiting centrifugal forces) or hydraulic (exploiting the pressure variation of the oil in a rotary pump).

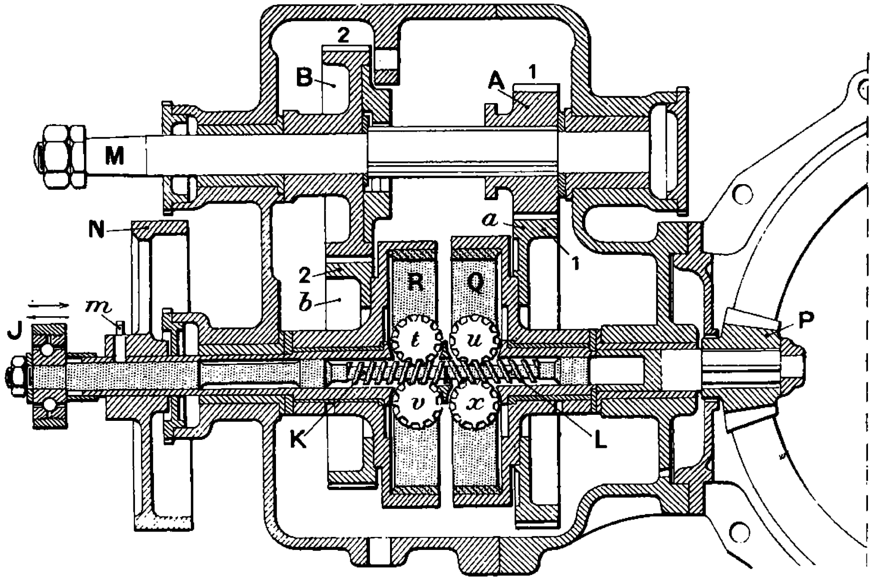

FIGURE 8.16. The De Dion & Bouton gearbox can be considered as a precursor to power-shift gearboxes. By shifting the shaft with the bearing J, it is possible to engage one of the two shoe clutches available on each gear; a start-up clutch is not necessary.

Today this problem appears in a new context, because electronic microprocessors allow easy automatization of synchronizers and friction clutches, in use on manual gearboxes; many existing vehicles already testify to this statement.

The first step was the development of gearboxes where speed shifts were possible without danger to tooth wheels and parts to be synchronized.

From this point of view we can consider as a precursor the manual gearbox of de Dion & Bouton, developed at the beginning of the past century and shown in Fig. 8.16.

This single stage gearbox has but two speeds; we can see at the left upper the input shaft and on the lower right the output shaft, which moves through a bevel gear the pinions of the chain drive.

The two gear always mesh, with the driven wheels idling on the output shaft; the wheel engagement is made by shoe clutches, similar to that already discussed in Fig. 8.14; these are controlled by the screws moving the gears t, v, u and x.

By shifting the shaft with the thrust bearing J, it is possible to engage one clutch and to disengage the other.

In this transmission, a start up clutch is not used during gear shifts.

Although developed for manual gearboxes, this kind of clutch is surely a relevant precursor of the powershift gearbox with band brakes and multi disc clutches.

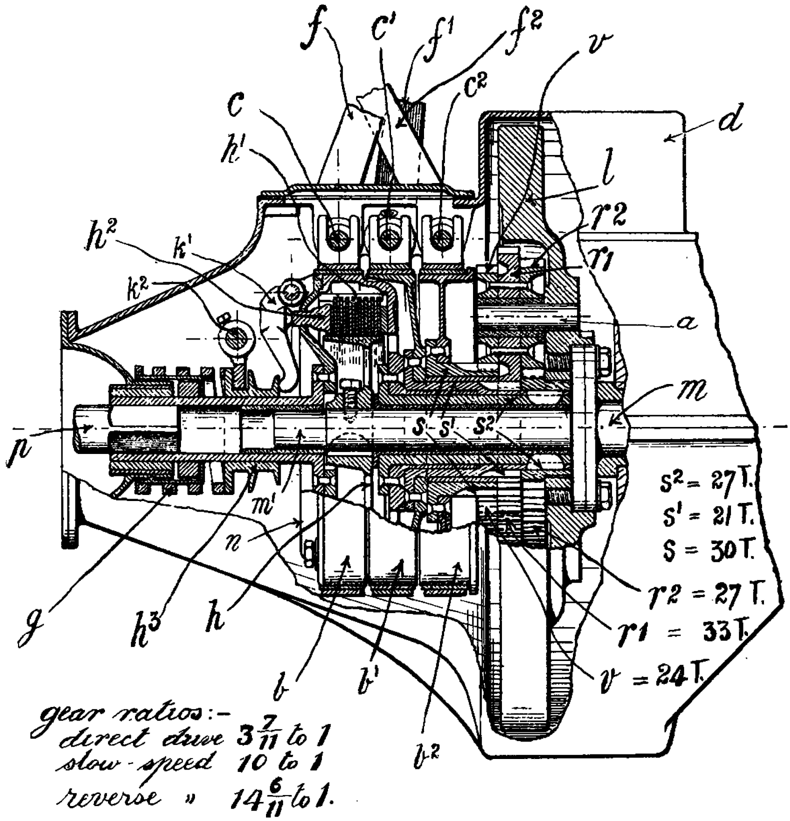

FIGURE 8.17. Epicycloidal gears gearbox of Ford model T of 1908. One reverse, one reduced forward speed and a direct drive are available.

A second gearbox of historical relevance is that of the Ford Model T of 1908, the first car to be produced in the millions.

Figure 8.17 shows a section of this gearbox; it is made with epicycloidal gears, instead of gears with a fixed rotation axis.

These gears did not originate with Ford, for they were already known in other applications. The epicycloidal gearbox may have been invented by Bodmer in 1834, although there is evidence that these mechanisms were already known to the ancient Greeks in applications for astronomical computations.

In this figure we see the three satellites v, r^1 and r^2 (the unusual position for the subscript, not to be confused with an exponent, is drawn from an original figure), rotating on a single carrier, fixed to the engine flywheel. These mesh with the corresponding sun gears s, s^1 and s^2.

If we imagine keeping the sun s stopped, by rotating the flywheel and the carrier we obtain a reduced output speed in the opposite direction, at the sun gear s^2, fixed to the output shaft.

On the other hand, by keeping the sun s^1 stopped, we can obtain a reduced speed in the same direction, again at the sun s^2; in the figure a note reports the transmission ratios that were obtained, including the differential transmission ratio.

If the multi disc clutch h^1 is engaged by shifting the sleeve h^3, it is possible to put the gearbox in direct drive by fixing the hub h, rotating with the crankshaft, with the output shaft.

To obtain the different states of the gearbox, the sun gears rotate with the drums c, c^1 and c^2, which can gradually be stopped with their band brakes; band brake control is performed by front cams, moved by pedals on the car dashboard; the lower part of these pedals is shown in the figure with the letters f, f^1 and f^2.

The pedals have a spring system that makes them stable either in the released or depressed position; each pedal raises if the other is depressed.

When engine and car are stopped, the pedal f must be depressed and the clutch h engaged; in this way the vehicle is in park condition.

By releasing the clutch h, through a lever, the engine is disengaged and can be cranked. The car is still stopped.

By depressing one of the pedals f^1 or f^2, the pedal f is raised, the car is left free to move and will be started-up in low gear forwards or backwards; speed inversions can also be made by a moving vehicle, and start-up on slopes is made easier.

As soon as the suitable speed is reached, by engaging the clutch h the pedal f^1 will be released, obtaining direct drive.

The gearbox is controlled by driver actions, but clutch management is performed automatically during gear shifts.

From this scenario to a fully automatic gearbox the way was long, but these achievements brought the final result closer.

The configuration of this gearbox allows us to understand why epicycloidal gears were preferred to conventional ones for the new automatic transmissions: Because of the ease of integrating brakes and clutches.

A further step was made by Wilson, in England, in 1928, who proposed a gearbox made of two different epicycloidal gear trains in series, in which the carrier of the first gear was connected to the ring of the next gear. With two gears it is possible to obtain three speeds forward, one of them being a direct drive and a reverse speed.

The three speeds were obtained by braking drums with bands, as in the Ford gearbox; a schematic example of the Wilson gear train is shown in Fig. 8.20, in the chapter dedicated to automatic transmissions.

These gearboxes, similar in use to those of the Model T, were semi-automatic with manual preselection; according to this concept, a small lever near the steering wheel was used to select in advance the next gear to be used. At this point no gearshift commenced, but the brake mechanisms were arranged for the gearshift to be made. This occurred as soon as the driver depressed a pedal for this purpose, set in the position normally used for the clutch pedal.

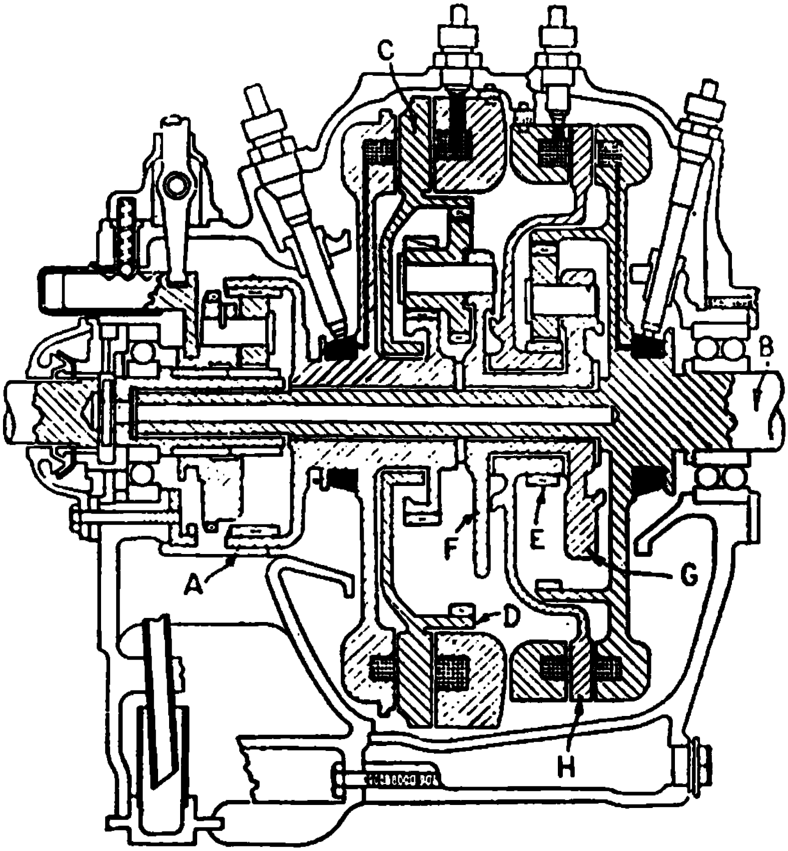

FIGURE 8.18. Semi-automatic gearbox produced by Cotal from 1934. The different elements of epicycloidal gears are braked by electromagnets; the reverse is engaged manually.

The driver was supported, in this way, in executing a coordinated maneuver of the gear stick and clutch; the energy for this function was still produced by driver muscles through a pedal.

A particularly advanced semi-automatic gearbox was introduced by Cotal in 1934, in France; Fig. 8.18 shows a cross section of this gearbox.

This gearbox includes three epicycloidal gears; the engine is on the left, the output shaft on the right.

Toroidal electromagnets can stop elements of the gear train; in particular, the first puts the corresponding gear set into direct drive, by fixing sun and ring gears together; the second obtains a reduced speed. At right, the third electromagnet obtains a faster speed, while the last achieves direct drive.

By energizing electromagnets in combination, two reduced speeds, a direct drive and an overdrive can be obtained.

A small switch with five positions, set near the steering wheel, allowed the four ratios to be obtained automatically, without use of clutches, whose function was controlled by electromagnets timing and inertia of parts accelerated or slowed down during shifts; the fifth position was for the idle gear, with all electromagnet circuits open.

The first epicycloidal gear on the right is operated, instead, manually, when the car is stopped and the transmission in idle position; a control lever moves the carrier back and forth, which can engage with the ring gear, obtaining a forward speed, or can be stopped, obtaining a reverse gear. Vehicle motion can be obtained, after this manual shift, with the first gear, controlled by its electromagnet.

The most relevant inconveniences of this gearbox were its heavy weight and large size.

Semi-automatic Wilson and Cotal gearboxes were used primarily by European manufacturers specializing in luxury cars; the Second World War crisis caused many of these manufacturers to disappear, these transmissions with them.

The final step towards modern automatic gearboxes was taken by exploiting hydraulic torque converters.

The torque converter had been introduced by the German naval industry, after the invention of Föttinger in 1905, well before its application in cars.

He patented a torque transmission system using a centrifugal pump and a turbine, in the same hydraulic circuit. With this device, the torque transmission is obtained by the momentum variation of the flow through the rotating blades, and is also possible when the pump (the engine) is rotating and the turbine (the vehicle) is stopped.

The idea was developed further through the design of an integrated device of reduced dimensions almost interchangeable with the conventional friction clutch.

In 1910, a patent for a hydraulic clutch simplified by the elimination of the reactor element was filed.

Again in Germany, in 1928, the research consortium Trilok developed the homonymous torque converter, able to obtain in a single machine the performance of the torque converter and the hydraulic clutch. This was done by mounting the reactor element with a freewheel.

The first automatic gearbox developed for a car was produced by GM; called the Hydramatic, it has been produced since 1939: A cross section of this gearbox is shown in Fig. 8.19.

In this figure, starting from the left side of the engine, we can see the hydraulic clutch, followed by three epicycloidal gear trains, able to obtain three forward speeds and a reverse speed; engagements and disengagements are obtained by two band braked (37 and 16) and two multi-disc wet clutches (7 and 17).

Brakes and clutches are operated by oil pressure, generated by the gear pump 33 on the front side of the gearbox, and modulated both by servo valves and a manual control on the steering wheel.

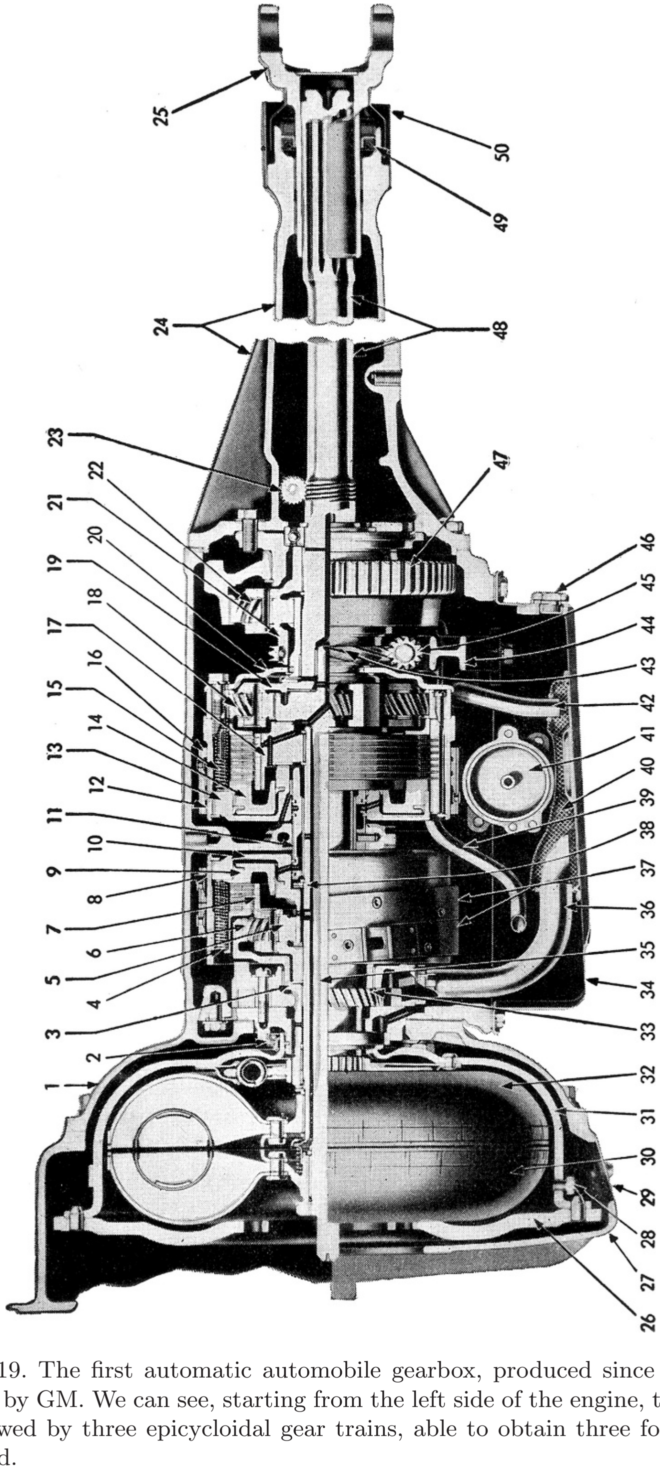

FIGURE 8.19. The first automatic automobile gearbox, produced since 1939, is the Hydramatic by GM. We can see, starting from the left side of the engine, the hydraulic clutch, followed by three epicycloidal gear trains, able to obtain three forward and a reverse speed.

Gear shift automatization is based upon the comparison of oil pressure generated by this first pump (dependent on engine speed) with a pressure generated by a second pump driven by the transmission output shaft (dependent on vehicle speed). The difference between these two pressures is used to move the gear shift servo valve; this valve is also made sensitive to the accelerator pedal position through a spring loaded mechanical link.

This system worked quite well on plain roads, upshifting speeds at higher vehicle speeds with higher accelerator compression; on slopes or on bending roads the automatic control had to be corrected by the manual selector.

We can notice that the hydraulic clutch is always subject to the engine torque; the clutch was used for start-ups and to dampen driveline torque vibrations.

The bulk of these gearboxes was absorbed by war production; only in 1946 did their application on commercial cars commence, to the appreciation of the public.

The Dynaflow gearbox, also from GM, has been produced since 1948. It introduced many improvements over the previous model (Fig. 8.20). The epicycloidal Wilson gear train, much simpler, allowed three forward and a reverse speed to be obtained, with two band brakes and a multi-disc clutch used in combination.

The most relevant step forward was the introduction of a refined torque converter, featuring a two stage reactor on freewheels; with this device it was possible to start-up the car with a torque transmission ratio greater than two (instead of one, by definition the ratio on the hydraulic clutch), allowing in the meantime the torque converter to function as a clutch, with better efficiency when input and output torques on the converter were equal.

This scheme is still present in automatic gearboxes, even if the need for a higher number of transmission ratios has justified the application of additional epicycloidal gear trains.

It is also interesting to remember the automatic gearbox designed in 1949 by the Dodge Division of Chrysler, with very original features.

Figure 8.21 shows the clutch of this gearbox; it includes a hydraulic clutch and a pedal friction clutch in series. Some gear shifts always demand a pedal clutch, but they are rare, thanks to a particular automatization device.

The twin friction and hydraulic clutches allow transmission vibration dampening and a smooth start-up, even if the pedal is released without particular skill; in addition, the car can be kept stopped on a slope simply through the use of an accelerator pedal. The next start-up is considerably easier.

Similar twin clutches were also applied in combination with conventional manual gearboxes on some European cars, such as the Fiat 1900.

The gearbox is explained in Fig. 8.22; it should not be confused with a simple counter shaft gearbox.

The main difference consists in the constant mesh wheel mounted with freewheel that allows torque to be transmitted to the countershaft, but not vice versa, and on a disengagement sleeve of this freewheel on the countershaft; it is

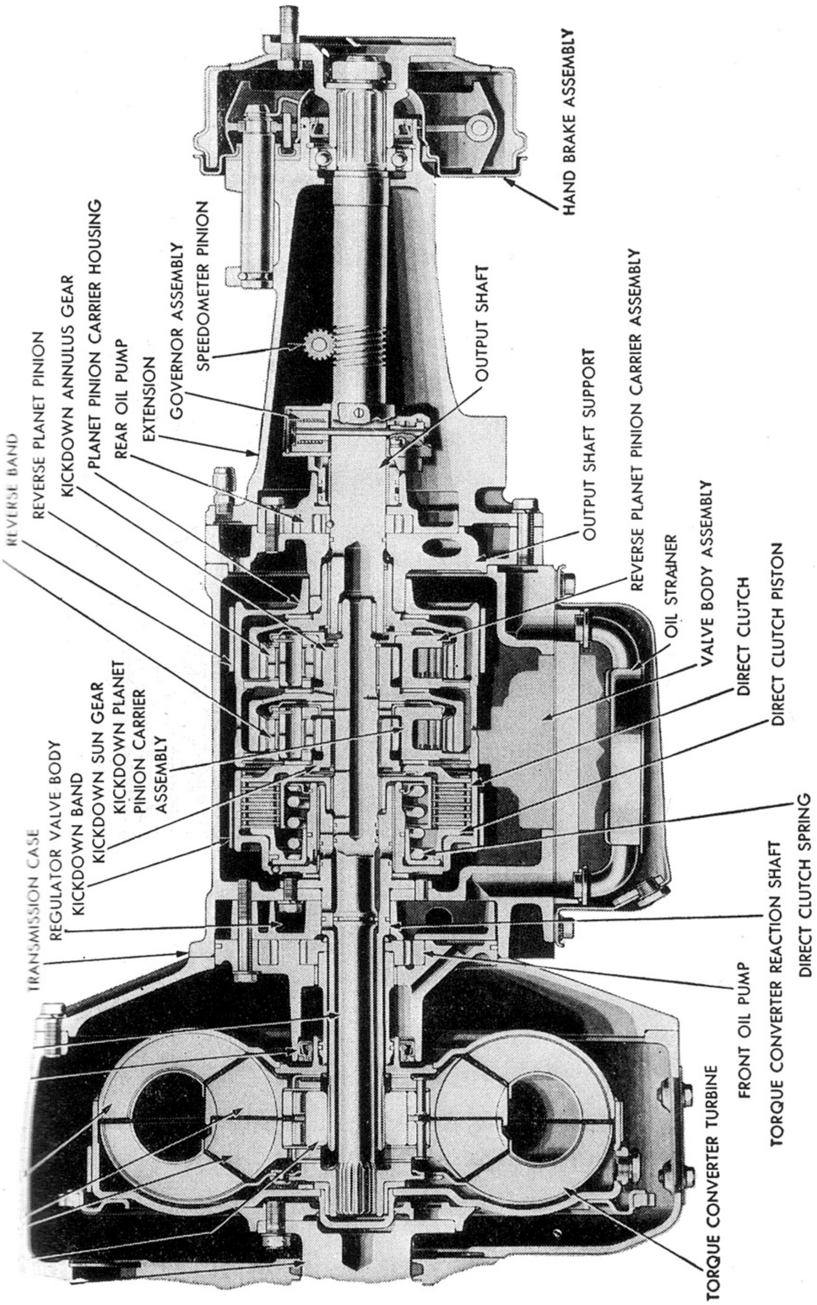

FIGURE 8.20. The Dynaflow gearbox, again by GM, has been produced since 1948 and can be considered an improvement over previous design. The Wilson epicycloidal gear train allows three forward and a reverse speed.

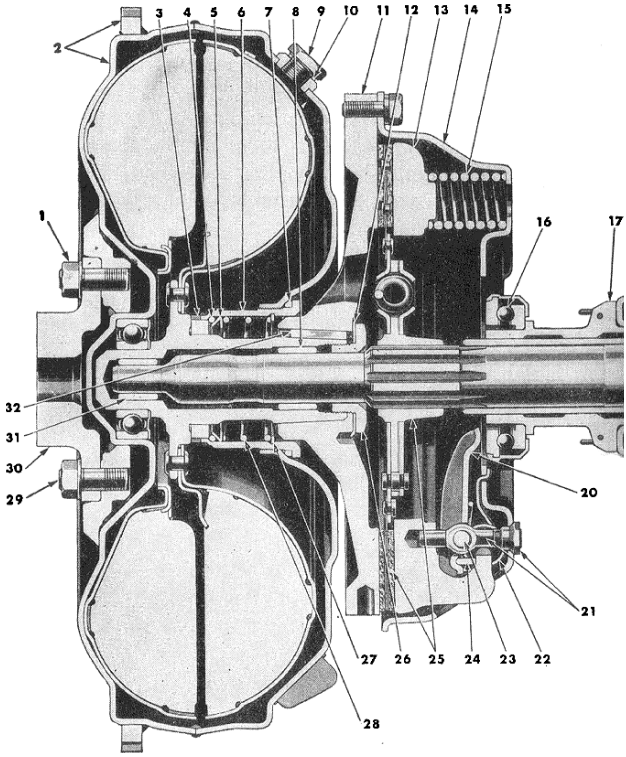

FIGURE 8.21. Hydraulic clutch of the Gyromatic semi-automatic gearbox, produced since 1949 by the Dodge Division of Chrysler; we can also see a conventional friction clutch with pedal control.

in the disengaged position in the first figure on the left. The whole set of figures represents the different gearbox states.

The gearbox control features a manual lever working on the sleeve, on the right of the output shaft, through a suitable leverage; if this sleeve is set to the left, first and second speeds can be obtained; if it is set to the right, third and fourth speeds are achieved.

This maneuver should be made by disengaging the friction clutch. Transmission ratios and engine displacement were such as to justify low speeds on slopes or in urban driving, while the remaining gears were recommended for suburban driving, including related start-ups.

Upshifts from first or third gear and downshifts from fourth or second gear were made automatically, by a tachometer device shifting the freewheel sleeve. Notice that when the gearbox is in the low gears, the third speed gear acts as a separate constant mesh gear.

These speed shifts did not require clutch disengagement because of the properties of the freewheel: The figures represent the positions in first and second

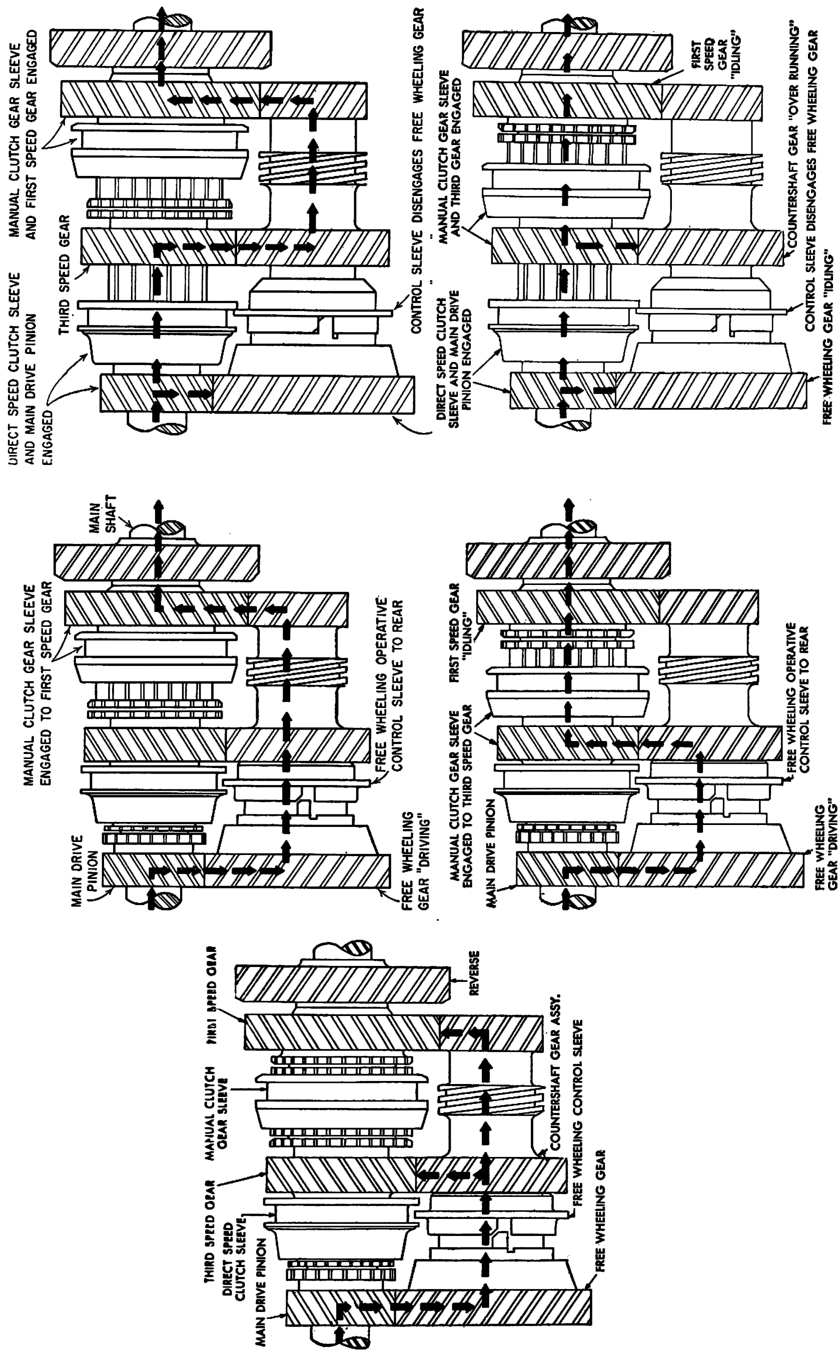

FIGURE 8.22. Scheme of Chrysler's Gyromatic gearbox. The gearbox has a manual control to select a low (first and second speed) and a high (third and fourth speed) speed range. Speed shifts from first to second and from third to fourth and back are fully automatic.

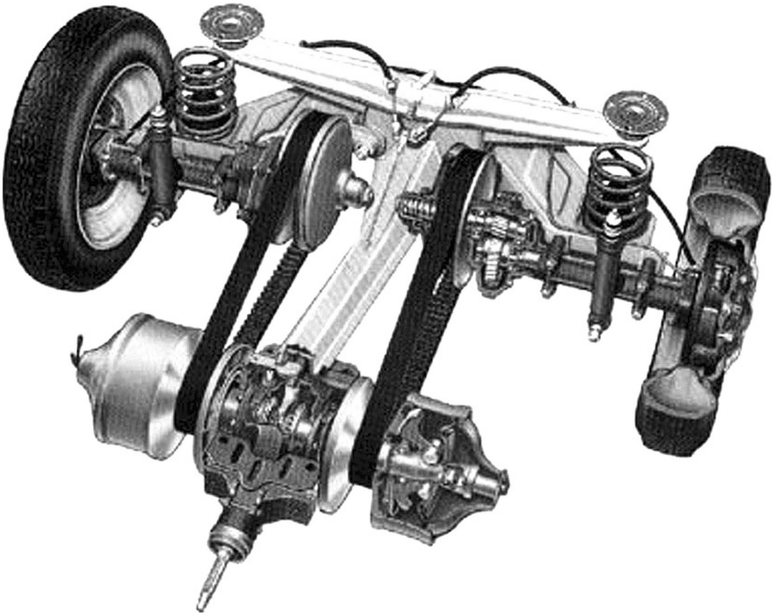

FIGURE 8.23. Automatic Variomatic transmission of the DAF Daffodil of 1950. It is made by expandable pulleys and rubber belt, reinforced by cords.

speed (on the upper row) and of third and fourth speeds (on the lower row). The first figure at the left represents the idle position.

Dotted lines represent the power flow at different speeds; the reverse speed was obtained by shifting an idler to engage the smallest wheel on the countershaft, with the largest on the output shaft.

A particular European contribution to automatic gearbox development was introduced by DAF Daffodil, with the Variomatic transmission of 1950. This transmission was probably the first reliable application of the continuously variable transmission to a car.

This transmission suitable for front engine, rear drive cars is shown in Fig. 8.23; the engine drove two expandable steel pulleys through a transmission shaft and a differential. These pulleys drove similar pulleys connected to the driving wheels.

The sides of the driven pulleys were compressed by coil springs that guaranteed the correct friction with a rubber belt; the sides of the driving pulleys were, instead, compressed by centrifugal masses and engine manifold pressure. Through this device speed ratio variation took into account engine speed and required torque.

A centrifugal friction clutch made car start-up completely automatic.

This transmission received no further application because of its strong impact on vehicle architecture.

The concept was completely reworked by Van Doorne (the DAF holding company), introducing a complete redesign. This study had as its objective the development of a steel belt variable transmission of reduced dimensions, capable of being interchanged with conventional manual gearboxes. An experimental application was made by Fiat and Ford and followed later by mass production.

This kind of automatic gearbox has now received a number of applications on different car brands.